10.0 NUTRIENT SOURCES

It has been shown that groundwater is a contributor of nutrients to Lake Tahoe. The nutrients may come from several sources throughout the basin. Each of the primary sources are discussed in this section. The key sources evaluated are fertilized areas, sewage, infiltration basins and urban infiltration. No direct correlation is made to application of nutrients to the soil and the associated effects on groundwater. Rather, this section provides information on those sources which may be contributing to the nutrient concentrations in groundwater. Nutrients are also present in the natural system and will contribute to the concentrations in groundwater.

10.1 Fertilizer

Fertilizer use has received increasing attention as a potential source of nutrient loading into the Lake Tahoe watershed. The nutrients provided by fertilizers to enhance plant growth can also cause algae in the lake to bloom (Welch 1992). The annual application of fertilizers in the basin can provide a regular source of nitrogen and phosphorus into the watershed. Algal growth in Lake Tahoe is limited by the availability of phosphorus in the Lake Tahoe Basin (Hatch 2001). The following report section will examine fertilizer use in the Lake Tahoe Basin and its potential availability to groundwater.

10.1.1 Historical Fertilizer Usage in Lake Tahoe Basin

Historical fertilizer use in the Lake Tahoe Basin is largely undocumented. In 1972, representatives from the University of California, Davis conducted a study to determine fertilizer use in the Lake Tahoe Basin (Mitchell 1972). The report found that the principal areas of fertilizer use in the Lake Tahoe Basin were golf courses, school grounds, landscaped areas around motels, condominiums, permanent resident homes, and agricultural areas. The report estimated fertilizer use by homeowners from application instructions and land areas. Fertilizer use in managed areas such as schools and golf courses was taken from available reports and interviews. The 1972 study found that fertilizer use added approximately 48 metric tons (53 tons) of nitrogen and 7 metric tons (8 tons) of phosphorus to the basin annually. In a 1986 article discussing algal biofouling in Lake Tahoe, topical applications of fertilizer input 79.3-84.6 metric tons (87.4 – 93.3 tons) of nitrogen and 26.4-28.2 metric tons (29.1 – 31.1 tons) of phosphorus to the lake annually (Loeb 1986). Other than providing a quantity range for fertilizer nutrient loading to the entire Lake Tahoe Basin, the 1986 article supplied no other details concerning fertilizer application nor did it provide a reference for the quantity information. Due to the uncertainty associated with the 1986 data at this time, the detailed 1972 report will be used as the primary historical fertilizer loading comparison for this report.

More recently, several steps have been initiated to limit the use of fertilizer in the Lake Tahoe Basin. The Tahoe Regional Planning Agency (TRPA) has worked to end the use of fertilizers in shore zone areas and stream channels while monitoring heavy fertilizer users in the basin (TRPA 2002a). The TRPA requires that large fertilizer users write or generate and submit Fertilizer Management Plans. These larger users include golf courses, parks, cemeteries, plant nurseries, recreational ball fields, and large residential yards with an acre or more of turf (only the Fertilizer Management Plans for golf courses were available for this Groundwater study). Since algae growth in Lake Tahoe is limited by phosphorus availability, the TRPA discourages the use of fertilizers that contain phosphorus. When a Fertilizer Management Plan submitted to the TRPA suggests the use of phosphorus, justification for the use of the fertilizer shall be included. As recently as November 2002, the TRPA Advisory Planning Commission was discussing a ban on phosphorus fertilizers in Tahoe (TRPA 2002a). Until such rigid guidelines are in place, users of fertilizer in the Lake Tahoe Basin are directed to use the TRPA, "Handbook of Best Management Practices" or the "Home Landscaping Guide for Lake Tahoe and Vicinity" (HLG) published by the University of Nevada Cooperative Extension (University of Nevada Cooperative Extension 2001). For this report, the rate of fertilizer loading in the Lake Tahoe Basin was in part determined using suggested rates in the HLG.

10.1.2 Fertilizer Composition

Fertilizers provide the essential nutrients required for plant growth. Nutrients provided in fertilizers include nitrogen, phosphorus, and potassium. Purchased fertilizers generally are associated with a sequence of three numbers that stand for the weight percentage of nitrogen, phosphorus, and potassium that are in the fertilizer, respectively. For example: if 4,540 grams (10 pounds) of a fertilizer rated 15-30-15 were applied to an area, the area would receive 680 grams (1.5 pounds) of nitrogen, 1,400 grams (3 pounds) of phosphorus, and 680 grams (1.5 pounds) of potassium. Because they have a greater impact on lake water clarity (Welch 1992), this report will focus on the nitrogen and phosphorus in fertilizers. In a fertilizer, some of the nutrients may be in more soluble forms that would be more quickly available for plant utilization. Due to the limited amount of information available, this section will focus on the mass of nitrogen (N) and phosphorus (P) applied rather than solubility of various forms of N and P.

Nitrogen

Nitrogen movement in the environment is very complex due to being stored and cycled in several forms. Nitrogen is generally found in four forms in soils and sediments: nitrogen gas, organic nitrogen, ammonium-ammonia, and nitrate (Novotny 1994). Nitrogen gas comprises approximately 80% of the atmosphere, but nitrogen must be converted to a plant-usable form by biological or light-energized reactions. Only specialized organisms have the ability to fix nitrogen gas (N_2) into a form usable for growth. Organic nitrogen is generally retained by organic matter until mortality and degradation. Both nitrate (NO_3^-) and ammonium (NH_4^+) are among the most utilized forms of nitrogen by plants (OSUE 2003). Nitrate, and to a lesser extent ammonium, is soluble and readily transported into groundwater.

Phosphorus

Compared to nitrogen, phosphorus is considered less mobile in the environment. Phosphorus found in the environment can come from several sources that include natural weathering of phosphate minerals, fertilizers, sewage, and phosphate detergents (Novotny 1994). Inorganic forms of phosphorus, such as aluminum, iron, and calcium phosphates, are somewhat inefficient for plant uptake due to their low solubility. To compensate, fertilizers are often added to raise the surrounding concentration to ensure some concentration is available for plant growth. Additionally, more soluble forms of phosphorus can be applied to meet plant requirements for growth. The general form of phosphorus applied to plants is phosphate (PO_4^{3-}), which is a soluble form of phosphorus (Schulte 1996). Since phosphorus itself is relatively insoluble, little phosphorus has the potential for leaching into groundwater until the soil is saturated. Locations that have received ongoing phosphorus applications are more likely to be in a saturated state. Once a soil area is saturated, a considerable amount of leaching can occur. In areas that have been fertilized and have not undergone erosion, soil removal, or crop removal, the concentration of phosphorus can remain elevated.

10.1.3 Fertilizer Nutrient Leaching

Nitrogen Leaching.

Nitrogen leaching is a means for nitrogen to enter and be transported by groundwater. While this report does not determine the amount of nitrogen transported into the groundwater, it does provide the amount of nitrogen from fertilizer that is applied to the soil in the Lake Tahoe Basin. Often the types of fertilizers applied to improve plant growth are soluble, enhancing the potential for nitrogen leaching into groundwater.

Phosphorus Leaching.

For this report a simplified phosphorus-leaching model was utilized in order to estimate the availability of phosphorus for groundwater infiltration. The calculations are based on a Langmuir adsorption model (Novotny 1994). Some assumptions were made in order to estimate the buildup of phosphorus which included: that there were long periods of watering, a linear partitioning (isotherm) concept was applicable, and that the moisture content of soil was equal to the porosity (~40%). Using the model, the partitioning of phosphorus between the dissolved and adsorbed phase was determined. Additionally, the time for saturation (and breakthrough) could be determined for an assumed soil depth. The equations used for the model and the values applicable for soils in the Lake Tahoe Basin (USDA 1995) are listed below:

$$Q^o = -3.5 + 10.7(\%Clay) + 49.5(\%OrganicC) \qquad \text{(Equation 1)}$$

$$b = 0.061 + 170{,}000 \times 10^{-pH} + 0.027(\%Clay) + 0.076(\%OrganicC) \qquad \text{(Equation 2)}$$

$$\frac{R_a}{depth} = c_T = \left(\frac{Q^o bc_d}{1 + bc_d}\right)\rho + c_d\theta \qquad \text{(Equation 3)}$$

$$c_d = \frac{-\left(Q^o b\rho + \theta - bc_T\right) \pm \sqrt{\left(Q^o b\rho + \theta - bc_T\right)^2 - 4(b\theta)(-c_T)}}{2(b\theta)} \qquad \text{(Equation 4)}$$

$$\max saturation = Q^o \times \rho \times depth \times area \qquad \text{(Equation 5)}$$

$$Time = \frac{\max saturation}{\left(R_a - R_p\right)} \qquad \text{(Equation 6)}$$

where:

Q^o = The phosphorus adsorption maximum (in µg/g)

b = Adsorption energy coefficient (in L/mg)

c_T = Total inorganic P content of the soil

c_d = Dissolved inorganic P content in the pore water

θ = Soil moisture content

ρ = Soil Density (in g/L)

R_a = Rate of phosphorus application

R_p = Rate of plant uptake, assuming plants are harvested

depth = Assumed to be 7.6 centimeters (3 inches), the estimated root depth/mixing zone

Max saturation = maximum adsorbed P content for the soil

Time = Time required to reach soil saturation

Table 10-1. Lake Tahoe Soil Characteristics Applied to Phosphorus Model (USDA 1995)

Average Soil Characteristics	
% Clay	12.25
% Organic Matter	2.6
Soil pH	5.8
Soil Density, g/L	1337
porosity	0.4

Note: These values are based on basin-wide averages.

10.1.4 Fertilizer Application and Loading Rates

To quantify the amount of fertilizer applied in the Lake Tahoe Basin, several steps were taken. First, several categories of areas based on land use (TRG 2002) and their potential for fertilization were designated or established. Since only a portion of each land use area would receive fertilizers, the area fertilized in each land use category were determined or estimated. Next, the typical fertilizer loading/application rates were applied according to land use. From the loading rate and the land area of application values, the mass of fertilizer applied was then determined. Finally, the loading rates for single-family homes and golf greens were applied to the phosphorus leaching model (Equations 1 through 6) to determine the amount available for leaching into groundwater. Single-family home areas and golfing greens were specifically modeled due to their potential to include both regular watering and fertilizer applications.

Table 10-2. Estimated Fertilized Areas in the Lake Tahoe Basin

Category	Specific Use	Land Area, km^2	% of Area Estimated Fertilized	Area Fertilized, km^2
Residential				
	General	0.021	20	0.0045
	Single-family Residential	45	21	9.4
	Multi-family Residential	13	20	2.7
	Subtotal	59		12
Recreational				
	Golf Courses	4	95	3.8
	Urban Parks	0.29	50	0.14
	Subtotal	4.3		3.9
Institutions				
	General	2	20	0.41
	Schools	0.88	50	0.44
	Cemeteries	0.015	95	0.014
	Subtotal			
Commercial				
	Commercial	18	10	1.8
	Subtotal	18		1.8
Agriculture				
	Agriculture/Livestock	0.54	100	0.54
	Subtotal	0.54		0.54
Total		84		19

Notes:
1. 1 km2 = 247.1 acres

The land area categories determined for this report included the following: residential areas, recreational areas, institutional areas, commercial areas, and finally agricultural and livestock areas. The number of acres in each land area can be seen in Table 10-2. Residential areas include general areas, single-family homes, and multi-family homes. Recreational areas include golf courses and urban parks. Institutions include general areas (hospitals, libraries, government facilities, etc.), schools, and cemeteries. Commercial and agricultural areas were not broken into smaller categories. The method for determining the percent fertilized land area for each category was based on historical reports (Mitchell 1972) and sound judgment. This report assumes a scenario wherein fertilizer is applied to each area that can have it applied.

Fertilizer loading rates were based on land use characteristics. Generally the application rates suggested by the HLG were seen as the best case loading rates, while the worst case was assumed to be the utilization of a high nutrient fertilizer (in this case Miracle-Gro® All Purpose Plant Food). The suggested fertilizer utilization rate by the HLG uses a 20-7-7 fertilizer applied in the amount of 1,250 grams per 93 square meters (2.75 pounds per 1000 square feet), twice a year. The high nutrient (15-30-15) fertilizer is applied in 1,100-gram (2.5-pound) increments over 93 square meters (1000 square feet) bimonthly over 4 months as directed by the product label. Any additional knowledge of loading rates particular to a land use area is discussed within that land use section.

10.1.5 Residential

Fertilizer loading rates in residential areas were examined for single-family areas, multi-family areas, and general residential areas. The number of single family homes and their individual land areas were estimated from the single home land area for the basin (TRG 2002) and census data of housing (U.S. Census Bureau 2001). The fertilized portion of each residential lot was assumed to be 300 square meters (3,200 square feet) based on information from the 1972 fertilizer use study (Mitchell 1972). For the multi-family and general residential areas, the percent of fertilized area was an educated estimate or a careful estimate.

Fertilizer loading rates in residential areas were assumed to be based on the HLG and instructions from a commonly used high nutrient fertilizer. Fertilizer application according to the HLG was assumed to be the best case, while the application of a commonly found fertilizer according to its instructions was seen as the worst case. Attempts to determine more representative application rates by conducting phone interviews for this report were unsuccessful.

As expected, the amount of nitrogen and phosphorus applied using the high nutrient fertilizer was much greater than the amount resulting from using the HLG application rates. Assuming that the HLG application rates were followed, the Lake Tahoe Basin residential areas have the potential to annually receive approximately 64 metric tons (70 tons) of nitrogen and nearly 23 metric tons (25 tons) of phosphorus. If a high nutrient fertilizer were applied by single-family homeowners, then the nutrient loading in residential areas could swell to a potential 215 metric tons (237 tons) of nitrogen and nearly 410 metric tons (450 tons) of phosphorus. A complete breakdown of the estimated annual fertilizer loading rates in residential areas can be seen in Table 10-3.

Table 10-3. Annual Fertilizer Loading Rates For Residential Areas

Annual Grams of Nutrients per 93 square meters		
	N	P
Home Landscaping Guide (HLG)	500	180
High Nutrient Fertilizer	1,360	2,700

Useful planning information was obtained when the phosphorus-leaching model was applied to single-family possibly fertilized areas. For the model, it was assumed that landowners utilized grass clippings as mulch and reapplied it to their yards; therefore total removal of phosphorus by plant growth was eliminated. When areas were fertilized according to the HLG, the top 7.6 cm (3 inches) of soil were saturated in approximately 13 years and had a dissolved phosphorus concentration of nearly 30 μg/L. If a high nutrient fertilizer was applied according to directions, the top 7.6 cm (3 inches) of soil were saturated in one summer season (~ 4 months).

10.1.6 Golf Courses

During the early 1990's, golf courses began implementing Fertilizer Management Plans to both document and limit their fertilizer use (IVGID 2002). Many of the golf courses in the Lake Tahoe Basin submit annual reports documenting their fertilizer use during the previous year to the TRPA. Several annual reports were used to create a more accurate composite fertilization rate for the golf courses in the Lake Tahoe Basin (IVGID 2002, LTCB 1991). Depending on their use, different areas of golf courses will have appropriate fertilization rates. Table 10-4 indicates the percentage of fertilized area of greens, tees, fairways, and rough and their corresponding fertilization rates determined from several golf resorts in the Lake Tahoe Basin. The estimated amount of nitrogen and phosphorus applied yearly to golf courses in the basin were 52 metric tons (57 tons) and 16.7 metric tons (18.4 tons), respectively (Table 10-5).

Table 10-4. Golf Course Application Areas and Fertilizer Rates

	Portion of Golf Course, %	N Application Rate, grams per 93 m^2	P Application Rate, grams per 93 m^2
Greens	3	2,200	820
Tees	3	2,000	450
Fairways	22	1,500	410
Roughs	72	1,100	410

The phosphorus leachate model was applied to fertilized greens to determine the approximate dissolved concentration and determine the saturation time for 7.6 cm (3 inches) of soil. For the model, it was assumed that landscapers utilized grass clippings as mulch and reapplied it to their areas; therefore total removal of phosphorus by plant growth was eliminated. When areas were fertilized according to average green application rates the top 7.6 cm (3 inches) of soil were saturated in a little over 5 years and had a dissolved phosphorus concentration of 192 μg/L in pore water.

10.1.7 Urban Parks

The fertilizer loading rates in urban parks were obtained in a phone interview with a park representative. The loading rates obtained from a phone interview with the Tahoe City Public Utility District Park Superintendent (Russell 2002) are listed below. Calculations indicate that the amount of nitrogen and phosphorus applied to urban parks in the Lake Tahoe Basin were 2 metric tons (2.2 tons) and 0.27 metric tons (0.3 tons) respectively.

10.1.8 Institutions

Institutional fertilized areas include general areas (e.g., hospitals, libraries, and government facilities), schools, and cemeteries. For both general areas and cemeteries the fertilizer loading rate was in accordance with the HLG, using the assumption that landscaping professionals were knowledgeable of the HLG. Use of the fertilizing methods listed in the HLG for the fertilizable general and cemetery areas listed in Table 10-2 resulted in an annual basin loading of 6 metric tons (6.6 tons) nitrogen and nearly 0.9 metric tons (1 ton) of phosphorus. For schools in the Lake Tahoe Basin, fertilizer application was assumed to be at the rates stated by the Park Superintendent of the Tahoe City Public Utility District (Russell 2002). The annual loading of nitrogen and phosphorus to school areas is estimated to be 6.2 metric tons (6.8 tons) of nitrogen and 0.9 metric tons (1 ton) of phosphorus.

10.1.9 Commercial

Fertilizing methods listed in the HLG were applied to the potentially fertilized commercial areas listed in Table 10-2. Calculations resulted in an estimated annual loading of 8.9 metric tons (9.8 tons) of nitrogen and 3.1 metric tons (3.4 tons) of phosphorus in commercial areas.

10.1.10 Agriculture

Due to a lack of information, nutrient levels from agriculture and livestock were in accordance with those found in the 1972 report (Mitchell 1972). In 1972, average annual agricultural nutrient loading rates were found to be 4.5 metric tons (5 tons) of nitrogen and roughly 0.9 metric tons (1 ton) of phosphorus.

10.1.11 Summary

Current fertilizer application rates are thought to be much higher than estimates determined in 1972 (Table 10-5). The annual soil loading of nitrogen in the Lake Tahoe Basin has potentially tripled from approximately 48 metric tons (53 tons) in 1972 to a range of 143-295 metric tons (158-325 tons) today. The potential annual soil loading of phosphorus has increased approximately 7 metric tons (8 tons) in 1972 to at least 45 metric tons (50 tons) today. The current annual soil loading from fertilizer in the basin was expectedly greater than the nonverified values cited in 1986 (79.3-84.6 metric tons (87.4 – 93.3 tons) of nitrogen and 26.4-28.2 metric tons (29.1 – 31.1 tons) of phosphorus). The wide range of current nutrient loading in the basin was a result of simulating both a high and low nutrient fertilizer application in single-family residential areas. The assumption that fertilizer was applied by all land owners provides an estimate of the potential application of fertilizer in the basin by residents. Even at the recommended application rates, the potential amount of fertilizer applied by individual property owners is large. While this study liberally assigned fertilizer use to a portion of the land area of all single-family homeowners in the Lake Tahoe Basin, the values from the remaining land use areas are based on realistic rates. When considering only the application rates from recreational, institutional, and commercial areas, nitrogen application has increased roughly 230% while phosphorus use has increased over 400%.

Table 10-5. Estimated Annual Nitrogen and Phosphorus Application in the Lake Tahoe Basin in 1972 (Mitchell 1972) and Currently.

Category	Specific Use	Metric tons of Nitrogen 1972	Metric tons of Nitrogen Current	Metric tons of Phosphorus 1972	Metric tons of Phosphorus Current
Residential					
	General		0.027		0.009
	Single-family Residential		49.1-200.6		17.1-401
	Multi-family Residential		14.4		5.1
	Subtotal	13.6	64-215	1	22.2-406
Recreational					
	Golf Courses	26	51.8	4	16.7
	Urban Parks		2		0.27
	Subtotal	26	53.8	4	17
Institutions					
	General		5.8		0.8
	Schools	1.8	6.2	<0.36	0.9
	Cemeteries		0.18		0.027
	Subtotal	1.8	12.2	<0.36	1.7
Commercial					
	Commercial	2.3	8.9	<0.36	3.1
	Subtotal	2.3	8.9	<0.36	3.1
Agriculture					
	Agriculture/Livestock	4.5	4.5	0.9	0.9
	Subtotal	4.5	4.5	0.9	0.9
Total		~48	143-294	~7	45-429

* Ranges for current loading levels include loading rates using the HLG or a high nutrient fertilizer in single-family residential areas.
**The values are application rates. This does not represent the amount of nitrogen and phosphorus entering groundwater.

Phosphorus leaching calculations indicate that areas that are receiving regular doses of phosphorus may be saturated. Additional applications are more likely to increase groundwater infiltration without an increase in plant growth benefits. It is probable that phosphorus application could cease in areas that have been regularly fertilized (and have a plant clippings recycling program) with no decrease in plant growth.

The nutrient loading rates for the Lake Tahoe Basin that were determined for this report are only estimates. Additional studies are required to determine more accurate loading rates.

10.2 Sewage Exfiltration

10.2.1 Exfiltration

Exfiltration is the incidental outflow, or leakage, from sewer collection/flow pipes due to joints, cracks, holes, or breaks in the pipe. Collection systems are typically designed to account for a certain amount of leakage; average new construction allowable leakage rates range from 90 to 280 liters/day/cm-diameter/kilometer (100 to 300 gallons/day/inch-diameter/mile) of pipe. These averages are based on values provided by such sources as the EPA Sewer Manual, Engineering Contractors' Association Greenbook, and the American Society for Testing and Materials (ASTM) Standard for both asbestos cement pipe and vitrified clay pipe. TCPUD uses an even stricter standard of 9 liters/day/cm-diameter/kilometer (10 gallons/day/inch-diameter/mile) of pipe. Factors that affect exfiltration rates include: pipe age, pipe materials, normal vs. full flow in the pipe, and surrounding groundwater levels (USACE 2002).

Exfiltration can prove to be a problem because sewage carries high concentrations of nitrogen, phosphorous, fecal coliform, and many other potential contaminants. In the areas where leaks occur, the soil becomes saturated with these pollutants, thus potentially affecting water infiltrating through the soil, the groundwater, and eventually, the lake. A study has been conducted that shows a strong correlation between highly developed urban areas near the shore and high turbidity and chlorophyll measured in the lake; however, due to the particular testing methods used in the study, it is not possible to determine any exact sources, or causes, of the excessive turbidity and chlorophyll. A primary study of exfiltration rates for operating sewer systems was examined in the "Wastewater Collection System Overflow/Release Reduction Evaluation" portion of the overall Framework Study that attempted to estimate the amount of exfiltration that is occurring in the utility districts in both California and Nevada surrounding Lake Tahoe. This study, titled "Tahoe Basin Sewer System Exfiltration/Overflow Study", was conducted in 1983 by STPUD along with TCPUD and the North Tahoe Public Utility District (NTPUD) (USACE 2002).

In order to provide an accurate estimate of the amount of exfiltration that is occurring in the Tahoe Basin, testing conducted for the 1983 study included field testing 15 km (9 miles) of the 1,000 total kilometers (635 total miles) of sewer line in STPUD, TCPUD, and NTPUD using hydrostatic pressure methods. Results of this testing showed exfiltration rates averaging from 90 to 280 liters/day/cm-diameter/kilometer (100 to 300 gallons/day/inch-diameter/mile) of pipe; this data reflects expected exfiltration values based on accepted construction values. Once the field values had been collected, correction factors were used to determine average exfiltration rates; field testing was conducted in areas that were considered to have a high to medium risk of exfiltration based on pipe age, construction, and surrounding conditions. Correction factors were chosen to account for differences in flow conditions and hydraulic head, clogging of joints, steep slopes, high groundwater, and areas with less than 100 percent build-out. This factor was multiplied by the field values, which, in turn were multiplied by the applicable pipe diameter and length to produce the following table of exfiltration values (Table 10-6). (Nevada values were estimated based on estimated average unit exfiltration rates in California.)

Table 10-6. Average Unit Exfiltration Rate and Annual Exfiltration

District	Estimated Average Unit Exfiltration Rate[1] (liters/day/cm-diameter/kilometer of Pipe)	Estimated Annual Exfiltration[2] (Millions of Liters)
California		
STPUD	5.6	12
TCPUD	6.2	9.5
NTPUD	32.4	23
Nevada		
Incline Village General Improvement District	10.6	7.2
Tahoe Douglas District	10.6	2.3
Round Hill General Improvement District	10.6	1.1
Douglas County Sewer Improvement District Number 1	10.6	1.1
Kingsbury General Improvement District	10.6	2.3
Total		58.5

[1] Reflects only the correction factor for reduced hydraulic head
[2] Reflects only the adjustment for reduced hydraulic head correction factor

In the 1983 study, exfiltration rates for both sewer force mains and pump stations were determined to be zero. (USACE 2002)

The "Wastewater Collection System Overflow/Release Reduction Evaluation" recommends that the Corps use an average annual exfiltration rate in the Tahoe Basin of 58.3 million liters (15.4 million gallons) per year. Based on the concentrations of nitrogen and phosphorus in the sewage transported throughout the basin, the length and diameter of the pipes, and the *in situ* exfiltration rates of the sewers, it was determined that sewage exfiltration would contribute approximately 1,700 kg per year (3,700 lbs per year) of nitrogen and 470 kg per year (1,000 pounds per year) of phosphorus. These values were found to be insignificant based on previous studies that estimate the overall nutrient loading into Lake Tahoe of nitrogen at 400,000 kg/year (880,000 lb/year) and phosphorus at 43,600 kg/year (96,000 lb/year) (Reuter et al. 2002). However, when evaluating the sources of nutrients to groundwater only, sewer exfiltration may contribute ~5% of the nitrogen and ~13% of the phosphorus groundwater loading from anthropogenic sources.

10.2.2 Septic Tanks

The effects from decommissioned septic tanks on groundwater are unknown in the Lake Tahoe Basin. Until the early 1970s, many homes and businesses relied on septic tanks for wastewater treatment. STPUD and NTPUD were the only districts to have a treatment system in place before the banning of septic tanks in the late 1960s by the Porter Cologne Act. The decommissioning of the tanks included removing the contents and filling them with lime. The leach fields were typically abandoned in place.

Some research has been conducted on the effects of abandoned systems. Robertson (1998a, 1998b, 1996 and 1991) performed a series of studies on both active and decommissioned septic tanks in Ontario Canada, and given the similar cold climate, sandy to granitic soil, and steeper terrain, these studies are easy to compare to the Tahoe Basin. His studies found that nitrogen, mostly in the form of nitrate, returned to background values within one year of decommissioning. Conversely, phosphate persisted at levels that were virtually unchanged and the plume continued to migrate. Robertson realized that the phosphate behavior was dominated by sorption, which is rapid and reversible.

The study showed that 85% of the effluent concentration remained in the vadose zone. The remainder made its way to the groundwater zone. Here he noticed that 13% was adsorbed onto aquifer soils and the remaining 2% was present in solution. The partition coefficient, k_d values developed averaged 7.3 L/kg. Average phosphate concentration in septic tank effluent is about 9 mg/L. About 1 to 2 mg/L was found in the groundwater. Studying the rate of plume migration, a retardation factor of 20-100 was found, averaging 60. Although the migration was slow, Robertson found that the plume could eventually migrate over a long period of time with little or no reduction in concentration. The Province of Ontario has adopted a conservative approach when calculating phosphorus mass loaded to septic systems that is ultimately capable of migrating downgradient.

Using the assumption that the mass of phosphorus that moves into the groundwater table eventually will reach a receptor, mass of phosphate was calculated. A porosity of 0.4 and bulk density of 1.337 g/cm^3 were used in the calculation. If using the 7.3 L/kg k_d value from the Ontario study, the retardation factor is 25. If the average retardation factor of 60 is used, the k_d value calculated is 17 L/kg. A k_d of 7.3 - 17 L/kg and a retardation factor of 25 – 60 likely represents the range of k_d and retardation factor for phosphate in groundwater. A plume length for a household septic tank ranged from 0.3 meters to 25 meters (1 ft – 82 ft) (Robertson 1998b), averaging 7 meters (23 ft). The width and depth of the plume were assumed to average 10 meters (33 ft) and 2 meters (7 ft), respectively. The dissolved phosphate concentration found below septic tanks averaged 1.5 mg/L. Using these parameters, a phosphorus mass of 2.1 kg/tank to 4.9 kg/tank (4.6 lbs/tank to 11 lbs/tank) is estimated. Considering the use of septic tanks until the late 1960's, it was assumed that all households had a septic system. An estimate of 18,850 tanks in the Lake Tahoe Basin was determined from Census data. Using this estimate, the total phosphorus loading from septic tanks could range from 40 to 92 metric tons (44 to 100 tons).

Considering the tanks have been abandoned for about 30 years, many have assumed that septic tank loading may have already reached the lake. However, based on the estimated retardation factor of 25 to 60 for phosphorus, this may not be the case. Using an average hydraulic conductivity of 15 m/day (50 ft/day), a gradient of 0.02 and porosity of 0.4 it could take from 45 to 110 years for a plume to travel 500 meters (1,600 ft) to the lake. This assumes a steeper gradient than what will be found in many parts of the basin, South Lake Tahoe in particular. The nitrogen compounds are more conservative, typically advancing as quickly as groundwater. This implies that the nitrogen associated with septic systems may have already reached the lake. Using the same values as above, the nitrogen may have reached the lake as little as 1.8 years after the decommissioning.

10.3 Urban Infiltration

Urban infiltration results from the surface water runoff caused by snowmelt and rainfall flowing over impervious urban areas. These areas consist of such engineered structures as roads, parking lots, buildings, and sidewalks. Because water cannot infiltrate through these surfaces, the volume of runoff increases as it flows and then either collects in a storm water drainage system, or flows onto an adjacent permeable surface. The water can then be absorbed into the soil and flow into the groundwater, potentially acting as a facilitator of high nutrient or contaminant transport (LRWQCB 1995).

Typically in surface runoff situations, soils and vegetation remove or absorb many pollutants before they reach the groundwater or surface water of the watershed. In the case of urban runoff, however, water flowing over the impervious areas collects, carries, and deposits the pollutants when a permeable surface is encountered. Soil that is adjacent to these urban areas cannot alleviate this heavy concentration of pollutants, thus a higher concentration of contaminants is available to flow into the groundwater or lake. This higher concentration varies from season to season, but is particularly problematic during the first large storm of the fall/winter season after a long dry summer or the first large storm of the fall/winter season. During the summer, the contaminants have an extended opportunity to collect and become concentrated on the impenetrable surfaces. As the first large rainfall occurs, most of these collected contaminants flow with the runoff, and are deposited on the soil at one time. These particular rainfall events create important problems that should be considered when studying a watershed with a high percentage of urban infiltration (LRWQCB 1995).

The contaminants associated with urban infiltration depend upon land use (e.g., residential, industrial, construction, commercial), but typically include fertilizers, petroleum products, solvents, sewage or hazardous waste spills, animal wastes, and sediment. Many of the nutrient pollutants that cause concern within the Tahoe Basin are directly and indirectly associated with the abrasives and deicing compounds used on the roads and walkways during the winter. Another cause of nutrient pollution in this high altitude watershed is snowmelt. Runoff generated by the snowmelt carries atmospheric acids and nutrients, particularly nitrogen, that collect on the mountains during the snowfalls throughout the winter. The exact amount of nutrient pollutants that are contributed through urban runoff is impossible to quantify; it is truly a non-point source contributor, meaning the exact location of the pollution origin cannot be determined (LRWQCB 1995).

10.4 Engineered Infiltration Basins

Engineered infiltration in the Lake Tahoe Basin consists of all collected surface water runoff that is channeled to and collected in a man-made basin or wetland for the purpose of infiltration into the soil. Commonly used methods of infiltration in communities surrounding the lake are infiltration basins, infiltration trenches, dry wells, constructed wetlands and stream environment zones (SEZ). These engineered infiltration methods are becoming a popular means of preventing surface water runoff from freely flowing into the lake, thereby reducing the amount of suspended sediments and contaminants that are contributed to the lake by surface runoff. Despite the increased usage of engineered infiltration methods, it is still recommended that whenever possible, naturally vegetated areas be protected and used for infiltration of runoff from impervious surfaces. Plant-soil relationships are the most effective means for removing fine sediments, bioavailable nutrients, and other pollutants from urban storm water (LRWQCB 2001).

Infiltration practices recharge local groundwater supplies and help maintain vegetation. Onsite infiltration is particularly effective for phosphorus removal from surface waters (LRWQCB 2001), but little is known about the effect that these practices have on groundwater. It is possible that the phosphorus removal measured in the surface water is simply being transferred to the lake through the groundwater.

Infiltration systems convey surface water to groundwater regardless of quality. If not treated, storm water flows may negatively affect groundwater. Currently, no groundwater studies have been completed that prove infiltration systems do not have a negative impact on the nutrient concentrations in groundwater. Revision of water quality standards may be considered in the future (Whitney 2003). Soils can also become saturated with pollutants, reducing treatment capacity and creating a point source of contamination to groundwater. Infiltration systems may also alter natural groundwater flows by dewatering some areas and saturating others.

The following is a description of several engineered infiltration methods used in the Tahoe Basin:

10.4.1 Infiltration Basins

Infiltration basins are landscape depressions designed to capture runoff and infiltrate it directly into the soil, effectively removing fine sediments and some nutrients while providing groundwater recharge. Pollutant removal is achieved by sedimentation, physical filtration through soil surface horizons, and vegetative uptake. Infiltration basins also serve to attenuate peak flows to prevent downstream erosion (LRWQCB 2001).

Infiltration basins have been the principal method for storm water treatment in the Tahoe Basin for many years. Basins are generally applicable for storm water treatment in any area where land availability and site conditions permit. Constraints on basin location include anticipated sediment loading, soil type, percolation rates, depth to groundwater, and available maintenance access (LRWQCB 2001).

If properly designed and maintained, treatment basins can effectively trap sediment and, in some cases, remove bioavailable nutrients (primarily dissolved phosphorus) from surface waters. Infiltration systems convey surface water to groundwater regardless of quality, which may negatively affect groundwater. The water quality standard currently applied to storm water infiltration basins may not be stringent enough to protect the quality of groundwater (Whitney 2003). Infiltration may effectively remove nutrient and pollutant concentrations from surface waters, but in doing so conveys those same contaminants to groundwater which are also moving toward the lake. Suspended sediments accumulate over time in basins producing a concentrated source of nutrients and pollutants that can leach to groundwater. Other disadvantages of infiltration basins are that standing water can provide habitat for insect pests and may also present a potential safety hazard, especially for young children (LRWQCB 2001).

10.4.2 Infiltration Trenches

An infiltration trench is a shallow trench back-filled with gravel to allow for enhanced runoff of infiltration. Runoff is diverted into the trenches, from which it percolates into the subsoil. Vegetated conveyance swales may also serve as infiltration trenches. Infiltration trenches are most common along the drip line of elevated impervious surfaces, such as rooftops. Trenches used to drain large, heavily used paved areas, such as parking lots or other impervious surfaces should include pretreatment to remove heavy sediments and hydrocarbons (LRWQCB 2001).

Infiltration trenches have been shown to be very effective at infiltrating runoff and associated pollutants contained in storm water. Studies have suggested that expected pollutant removal effectiveness of infiltration trenches is 75% for sediment, 55% for phosphorus, and greater than 70% for trace metals, bacteria, and petroleum (LRWQCB 2001).

Again, infiltration trenches are pathways for nutrients and pollutants to make their way to groundwater in high concentrations, and become potential sources of nutrient loading to the groundwater. Infiltration trenches along roadways are particularly susceptible to pollutant runoff and infiltration. Pretreatment structures or source control methods should be used to prevent soil and groundwater contamination where pollutant concentrations are expected to be high (i.e., near roadways or parking lots) (LRWQCB 2001). Infiltration trenches are not favored by local residents or business owners because they tend to collect trash and require land constraints for acquiring property. Land acquisition is limited in the Tahoe Basin, making it difficult to install infiltration trenches (Whitney 2003).

10.4.3 Dry Wells

Dry wells are stone or gravel filled pits used to infiltrate runoff from impervious surfaces. Dry wells are well suited for treating small impervious areas as an alternative to infiltration trenches and may be appropriate on steeper slopes where trenches or other facilities cannot be installed. Dry wells are particularly appropriate to treat runoff from residential driveways or rooftop downspouts. As with other infiltration practices, dry wells should not be used in areas with high groundwater. Dry wells are not suited for treating runoff from large impervious surfaces such as parking lots. Pretreatment of runoff waters is recommended to prevent clogging by sediment and debris and to protect groundwater quality (LRWQCB 2001).

The City of South Lake Tahoe uses dry wells in areas with low discharge volumes. They are easy to install and inexpensive to maintain. El Dorado and Placer Counties often install rock infiltration basins with sand cans for pretreatment (LRWQCB 2001). However, dry wells may also provide a pathway for nutrients and other pollutants to more easily reach groundwater, negatively affecting groundwater quality and increasing nutrient concentrations.